Efficient Quantum Encoding Schemes for Quantum Image Processing

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Image processing and classification require efficient usage of resources to encode, decode, and classify an image for successfully leveraging the advantages of quantum image processing. During the MIT iQuHACK 2023, we have developed two efficient encoding schemes for an image from the provided data set based on the Flexible Representation of Quantum Images (FRQI) representation and the Novel Enhanced Quantum Representation (NEQR) as part of the IonQ-Remote Challenge using qiskit. Both these encodings convert an image into a quantum state for quantum image processing. The advantages of each encoding scheme have also been briefly highlighted.

I. INTRODUCTION

Leveraging the benefits provided by quantum image classification as opposed to classical procedures requires the development and implementation of efficient encoding schemes that convert a given image into a quantum circuit. For the IonQ remote challenge based on trapped ion quantum computing, it is essential to utilize encoding schemes that take into account the scalability challenge posed by trapped ion qubits. To implement the task of quantum image classification, our aim was to develop encoding schemes for the encoder, which converts a given image into a quantum circuit, and a corresponding decoder, which gives a histogram output for a given quantum circuit. We aim to use a quantum convolutional neural nets for performing the classification task as the method provides an efficient implementation using a shallow depth circuit. Our strategy prioritizes the following: (1) the encoding scheme to be as 'quantum' as possible, (2) optimizing resources for implementing the task, (3) improving the robustness of the process using relevant QEC and noise suppression schemes. In the following sections, we have briefly highlighted the concepts upon which we have based our quantum encodings for the encoder part of the challenge.

II. FLEXIBLE REPRESENTATION OF QUANTUM IMAGES (FRQI)

Using a polynomial number of simple gates, the FQRI encoding encodes the classical data into a quantum state to allow for further efficient operation to perform the classification task.

The main feature of FRQI is to have two pieces of information in relation to a pixel: the color of the pixel and the position of the pixel. The color of the pixel is prepared using $R_Y(2\theta)$ gates, while the position per each pixel is represented by a corresponding qubit.

For the given problem, we reduced the 28x28 matrix to 16x16 through downscaling, and each pixel is correspondingly encoded in qubits.

III. NOVEL ENHANCED QUANTUM REPRESENTATION (NEQR)

We have also used the NEQR scheme to perform the encoding, which differs from the above by using intensity values provided based on color coding. While it also uses a similar number of gate operations and qubits, it provides an additional advantage of generalizing to multiple colors, accuracy during image decoding as opposed to a probabilistic result from FRQI, and complex color coding options.

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